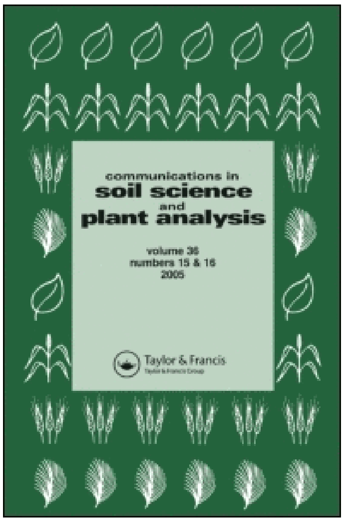

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Utilization of Existing Technology to Evaluate Spring Wheat Growth and Nitrogen Nutrition in South Dakota

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Utilization of Existing Technology to Evaluate Spring Wheat Growth and Nitrogen Nutrition in South Dakota

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Abstract: Sensor-based technologies for in-season application of nitrogen (N) to winter wheat (*Triticum aestivum* L.) have been developed and are in use in the southern Great Plains. Questions arise about the suitability of this technology for spring wheat production in the northern Great Plains. A field experiment was established in Brookings, SD, to evaluate the GreenSeeker Hand Held optical sensor (NTech Industries, Ukiah, CA) for predicting in-season N status on three spring wheat cultivars (Ingot, Oxen, and Walworth) across five N treatments. Nitrogen rates were 0, 34, 68, 102, and 136 kg N ha^{-1} applied preplant as ammonium nitrate. Sensor readings and plant biomass samples were collected at Feekes 6 and Feekes 10 growth stages. The sensor measures reflectance in the red and near infrared (NIR) regions of the electromagnetic spectrum. A normalized difference vegetation index (NDVI) was calculated. The ability of the sensor readings to predict biomass, plant N concentration, and plant N uptake for each sampling date was determined. In general, biomass, plant N concentration, and N uptake increased with increasing N rate for both sampling dates. Readings collected at Feekes 6 and Feekes 10 showed a significant relationship with plant biomass, N concentration, and N uptake for all varieties. Plant N uptake and NDVI resulted in a higher regression coefficients compared to biomass and plant N concentration for all varieties. Results suggest that existing sensor-based variable nitrogen technology developed for winter wheat could be utilized in the northern Great Plains for estimating in-season N need for spring wheat.

Keywords: Near infrared, nitrogen, precision agriculture, spring wheat

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INTRODUCTION

During the past 10–20 years, there has been a rapid increase of research in the area of precision agriculture. Precision agriculture can be defined as assessing and understanding the spatial and temporal variability within a field and applying management decisions based on this variability. The variability within a field can lead to nonuniform yields and/or uneven yield potential, resulting in areas of the field that should be managed differently for economical and/or environmental reasons. Spatial variability within a field exists for a number of different reasons, including soil types, landscape positions, past management practices, or other factors (Kincheloe 1994).

Previous management decisions frequently have been based on an average condition for a particular field or on the needs of the most limiting area. This management approach has resulted in some areas receiving more or less input than needed for optimum yield, which could contribute to increased environmental pollution from overfertilization, increased leaching, and runoff of nutrients. Precision agriculture has the potential to explain and overcome some of the spatial variability problems within fields. Tools now exist to help identify and manage different spatial zones according to the best management practice for each area, thereby decreasing the potential for environmental pollution.

One such technology is currently being marketed for topdress nitrogen (N) fertilizer for winter wheat (*Triticum aestivum* L.) in the southern and central Great Plains. Additional research is needed to advance this technology to other production systems, such as spring wheat in the northern Great Plains. Early research found that reflectance measurements (NIR/red ratios) could be used to estimate leaf dry matter or leaf area in spring and winter wheat (Aase and Tanaka 1984). Reflectance in the green region of the visible portion of the electromagnetic spectrum is a good indicator of N concentration in crops including corn (*Zea mays* L.), wheat, and bermudagrass [*Cynodon dactylon* (L) *Pers.*] (Blackmer, Schepers, and Varvel 1994; Walburg et al. 1982; Aase and Tanaka 1984; Blackmer et al. 1996). Stone et al. (1996) estimated total plant N concentration using spectral radiance measurements at the red (671 nm) and near infrared (NIR) (780 nm) wavelengths.

Recent research has found that plant N-use efficiency increased by topdressing winter wheat based on in-season sensor readings (NDVI) collected with a handheld instrument measuring every 1-m^2 area (Raun et al. 2002). These measurements can be utilized to estimate grain yield in season to determine N recommendations; results have found that in-season measurements explain 83% of the variability in measured grain yield (Raun et al. 2001). This technology has the potential of decreasing the environmental risks from overfertilization by applying N only where it is needed and/or at the locations most likely to respond to fertilizer N. Plant N-use efficiency was increased by 15% for fertilizer applied based on sensor readings compared to traditional methods. This research was conducted primarily in the southern Great Plains in winter wheat production systems; additional information is needed to expand this technology to other regions and production systems. The objective of our research was to evaluate this technology for predicting in-season N status and grain yield for three spring wheat cultivars (Ingot, Oxen, and Walworth) in the northern Great Plains.

MATERIALS AND METHODS

The experiments were located near Brookings, SD, on a Lismore silty clay loam (fine-loamy, mixed, pachic Udic Haploboroll) at the USDA, ARS, Northern Grain Insects Research Laboratory. Planting occurred on 11 April 2003 with spring wheat varieties Walworth, Oxen, and Ingot all at seeding rates of 530,000 plants ha^{-1}. The experimental design was a randomized complete block design with four replications. The treatments consisted of five N rates (0, 34, 68, 102, and 136 kg N ha^{-1}) applied preplant as ammonium nitrate. Plots were 3 m $\times$ 3 m with 0.18 m row spacing.

Sensor readings were collected at Feekes 6 (28 May) and Feekes 10 (9 June) growth stage (Large 1954) with a GreenSeeker Model 505 handheld optical sensor (NTech Industries, Ukiah, CA[1]). Sensor readings (NDVI) were collected at a height of approximately 1 m. A 0.3-m $\times$ 0.6-m area was scanned at each growth stage, and samples were taken for biomass production and N concentration. A separate 0.3-m $\times$ 0.6-m area was scanned at Feekes 6 and Feekes 10 that was left for grain yield estimation.

Biomass samples were dried for 120 h in a forced-air oven at 60°C and then weighed to obtain dry-matter production. Samples were ground to pass a 2-mm sieve. Total N concentration was determined using dry combustion (Schepers, Francis, and Tompson 1989). Nitrogen uptake was estimated by multiplying total N analysis and dry plant biomass. Grain yield was estimated by hand harvesting the 0.3-m by 0.6-m area scanned in season at both growth stages. Grain yield was calculated and corrected to 130 g kg^{-1} moisture. Statistical analysis was performed on plant biomass, plant N concentration, plant N uptake, and grain yield using the general linear models (GLM) procedure, and correlation coefficients between sensor reading and plant measurements were calculated using the correlation (CORR) procedure (SAS 1988).

RESULTS AND DISCUSSION

Plant Biomass and Grain Yield

Three popular South Dakota State University spring wheat varieties were chosen for this research project. Ingot is characterized as a very early

[1]Mention of trade name or commercial products in this publication is solely for the purpose for providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture.

maturing variety that has medium-size kernels and an average plant height of 94 cm, with a relatively high average test weight and grain protein (62.6 lb/ac and 15.0%). Oxen is characterized as an early maturing variety that has medium-size kernels and an average plant height of 81 cm, with an average test weight and grain protein (60.0 lb/ac and 14.8%). Walworth, a newer variety, is characterized as early maturing variety with medium- to small-size kernels, an average plant height of 84 cm, and an average test weight and grain protein (60.2 lb/ac and 14.8%).

There was a significant linear response to applied N for all varieties for plant biomass, plant N concentration, N uptake for both sampling dates, and grain yield (Tables 1–3). Biomass samples collected at the Feekes 6 growth stage resulted in Oxen having the greatest response to applied N, with a 93%

Table 1. Plant biomass, N concentration, and N uptake response to applied N, treatment means, probability of a significant treatment difference, and a linear response to N rate at Feekes 6 growth stage, Brookings, SD, 2003

N rate	Biomass ($kg\ ha^{-1}$)	Plant N ($g\ kg^{-1}$)	N uptake ($kg\ ha^{-1}$)
Ingot			
0	1589	27.2	43
34	1790	30.9	55
68	2314	35.4	82
102	2234	37.4	84
136	2355	38.7	92
Pr > f[a]	0.0354	0.0030	0.0075
Linear[b]	0.0046	0.0002	0.0006
Oxen			
0	997	28.1	28
34	1502	30.9	46
68	1691	36.8	62
102	1927	40.8	78
136	1793	42.9	77
Pr > f	0.0003	0.0001	0.0001
Linear	0.0001	0.0001	0.0001
Walworth			
0	1285	27.7	35
34	1826	32.1	58
68	2118	36.4	77
102	2323	43.1	102
136	2362	44.5	105
Pr > f	0.0008	0.0001	0.0003
Linear	0.0001	0.0001	0.0001

[a]Probability of a significant response to applied N.

[b]Probability of a significant single degree of freedom linear contrast to applied N.

Table 2. Plant biomass, N concentration, and N uptake response to applied N, treatment means, probability of a significant treatment difference, and a linear response to N rate at Feekes 10 growth stage, Brookings, SD, 2003

N rate	Biomass (kg ha^{-1})	Plant N (g kg^{-1})	N uptake (kg ha^{-1})
Ingot			
0	2642	15.7	42
34	3719	17.8	67
68	4745	20.8	98
102	3958	24.9	99
136	4831	25.3	122
Pr > f[a]	0.0182	0.0001	0.0004
Linear[b]	0.0044	0.0001	0.0001
Oxen			
0	2295	18.9	43
34	2963	20.9	62
68	3893	24.6	96
102	3827	26.1	100
136	3305	27.2	90
Pr > f	0.0002	0.0028	0.0003
Linear	0.0002	0.0002	0.0001
Walworth			
0	2980	16.1	48
34	3682	19.3	72
68	4493	23.7	105
102	4546	23.2	106
136	4765	27.8	133
Pr > f	0.0522	0.0016	0.0022
Linear	0.0056	0.0001	0.0001

[a]Probability of a significant response to applied N.
[b]Probability of a significant single degree of freedom linear contrast to applied N.

increase in biomass for the 102 kg N ha^{-1} N rate compared to the no-N treatment (Table 1). This variety had the lowest average biomass production compared the other varieties (1582 kg ha^{-1} versus to 1982 and 2056 kg ha^{-1} for Walworth and Ingot, respectively). Plant N concentrations were higher for Oxen and Walworth compared to Ingot, although Oxen had the lowest average N uptake, due to lower yields (Table 1).

At the Feekes 10 sampling date (Table 2), plant biomass production, plant N concentration, and N uptake were significantly different for all varieties. Sampling at Feekes 10 found that the greatest response to applied N was for Ingot with an increase of 82% for the 136 kg N ha^{-1} N rate compared to no-N treatment (Table 2). Oxen continued to have the lowest average

Table 3. Spring wheat grain yield response (kg ha^{-1}) to applied N, treatment means, probability of a significant treatment difference, and a linear response to N rate, Brookings, SD, 2003

N rate	Ingot	Oxen	Walworth
0	3572	3609	4262
34	4354	4820	5477
68	5119	5607	5569
102	5149	6078	5382
136	5196	5736	5304
Pr > f[a]	0.0082	0.0016	0.0260
Linear[b]	0.0012	0.0001	0.0347

[a]Probability of a significant response to applied N.

[b]Probability of a significant single degree of freedom linear contrast to applied N.

biomass production of the three varieties (3256 kg ha^{-1} compared to 3979 and 4093 kg ha^{-1} for Ingot and Walworth respectively). Similarly plant N concentrations were higher for Oxen and Walworth compared to Ingot, although because of lower yields Oxen had the lowest average N uptake (Table 2). Differences in biomass production at both growth stages corresponded to the general differences in plant height for the particular varieties, with Oxen having the lowest average plant height.

There was statistically significant linear response to applied N for grain yield for all varieties (Table 3). In contrast to plant biomass comparisons, Oxen had the lowest plant biomass for both sampling dates but did not produce the lowest average grain yield. The greatest response to applied N was from Oxen, for which the 102 kg N ha^{-1} rate yielded 68% higher than the no-N treatment. The lowest response to the addition of N was from Walworth, which had only a 30% yield increase for the 68 kg N ha^{-1} rate compared to the no-fertilizer treatment, also having the highest average yield. Ingot had the lowest average yield compared to the other varieties (4678 kg ha^{-1} compared to 5170 and 5198 kg ha^{-1} for Oxen and Walworth respectively).

Sensor Readings

Simple correlation coefficients for biomass, plant N concentration, N uptake, and grain yield with NDVI sensor readings by variety and a combination of all varieties at each sampling date are reported in Tables 4 and 5. All correlations were statistically significant at the 0.01 probability level except for the Ingot Feekes 6 growth-stage spectral NDVI readings with grain yield, although they were significant at the 0.05 probability level. Overall, the Feekes 6 growth-stage readings had higher correlations with in-season plant measurements

Table 4. Simple correlation coefficients from linear regression and significance levels for biomass production, plant N concentration, and N uptake, with NDVI spectral readings, Brookings, SD, 2003

Stages	Cultivar	Biomass ($kg\ ha^{-1}$)	Plant N ($g\ kg^{-1}$)	N uptake ($Kg\ ha^{-1}$)
Feekes 6	Ingot	0.82**	0.84**	0.89**
	Oxen	0.87**	0.80**	0.88**
	Walworth	0.84**	0.81**	0.82**
	Combined[a]	0.83**	0.74**	0.84**
Feekes 10	Ingot	0.70**	0.71**	0.73**
	Oxen	0.70**	0.82**	0.82**
	Walworth	0.69**	0.70**	0.73**
	Combined	0.62**	0.67**	0.71**

[a]Correlation coefficient for all varieties combined.
**, *Significant at the 0.01 and 0.05 probability level, respectively.

compared to the Feekes 10 readings (Table 4). There was not one variety for the Feekes 6 reading that had higher correlations compared to the other varieties for the plant component measured, whereas Oxen was the only variety with correlation coefficient greater than 0.80 for the Feekes 10 sampling date. Oxen was the variety with the lowest average biomass production. The combined correlation coefficients for all varieties were lower than the correlation coefficients for each individual variety. Generally the N uptake correlations were higher than the biomass production and plant N concentrations, regardless for variety or sampling date; therefore further analysis was performed.

Quadratic equations were developed for NDVI readings with plant N uptake for both sampling dates and are illustrated in Figures 1 and 2. Similar to correlation coefficients the Feekes 6 readings resulted in a higher quadratic regression coefficient compared to the Feekes 10 readings ($r^2 = 0.80$ compared to 0.61 for Feekes 6 and 10, respectively) for all varieties combined. Both sampling dates illustrate a significant quadratic relationship between sensor reading and plant N uptake.

Table 5. Simple correlation coefficients from linear regression and significant levels for grain yield with NDVI spectral readings, Brookings, SD, 2003

Cultivar	Feekes 6	Feekes 10
Ingot	0.58*	0.66**
Oxen	0.65**	0.74**
Walworth	0.63**	0.67**
Combined	0.51**	0.57**

**, *Significant at the 0.01 and 0.05 probability level, respectively.

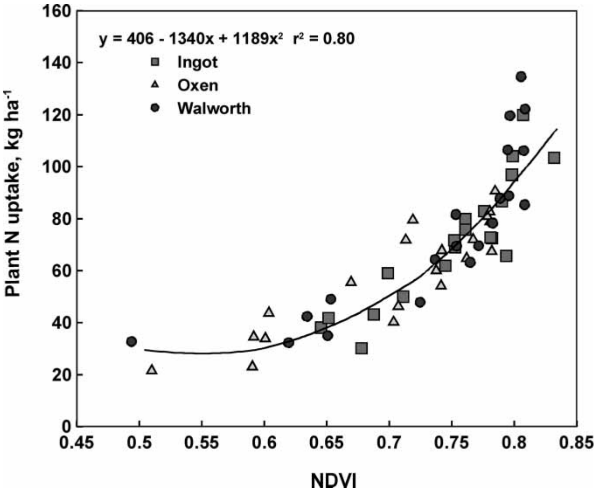

Figure 1. Relationship between sensor NDVI reading and plant N uptake for all N rates and spring wheat varieties at Feekes 6 growth stage, Brookings, SD, 2003.

Grain-yield correlation coefficient with NDVI readings found that readings collected at the Feekes 10 growth stage had higher correlation coefficient compared to the Feekes 6 sensor readings regardless of variety (Table 5). Oxen had the strongest correlation for both sampling dates (0.65 and 0.74 for Feekes 6 and 10, respectively). Similar to in-season plant components,

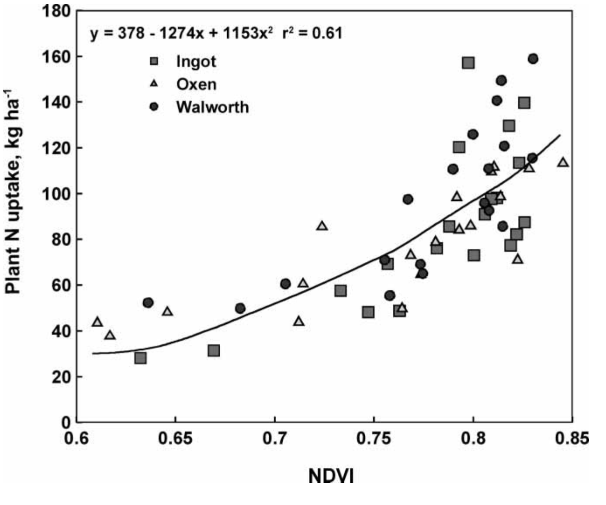

Figure 2. Relationship between sensor NDVI reading and plant N uptake for all N rates and spring wheat varieties at Feekes 10 growth stage, Brookings, SD, 2003.

the combined correlations had lower coefficients compared to the individual varieties.

CONCLUSIONS

Spring wheat response to application of N was significant, and plant components measured and grain yield generally increased with increasing applied N. The positive plant response to applied N demonstrated that a suitable location was chosen to evaluate the potential of utilizing the GreenSeeker as a possible tool to estimate in-season plant N status and grain yield for spring wheat production in the northern Great Plains. Sensor readings collected at two separate growth stages predicted plant N uptake, regardless of variety. However, the relationship between sensor readings and grain yield reported here were not as promising as previous research in winter wheat production systems in the southern Great Plains (Raun et al. 2001). Additional testing is needed to properly evaluate this sensor to determine the impact on N-use efficiency and its suitability in our growing conditions. Future research will evaluate the ability of the sensor under extremely different environmental conditions throughout the state of South Dakota.

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